

**The use of LACE<sup>TM</sup>, a listening program, in the treatment of  
problems associated with dichotic listening disorders.**

A Thesis

Presented in Partial Fulfillment of the Requirements for  
The Degree Bachelors of Arts in Speech and Hearing Science  
with Honors in Research Distinction in the  
College of Arts and Sciences of The Ohio State University

By

Mariah N. Cheyney

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The Ohio State University

2009

Dr. Gail M. Whitelaw, Adviser

## Abstract

Dichotic listening, or how two ears work together as a team, is critical for localizing sound sources and when listening in the presence of complex background noise. Disorders of dichotic listening can be caused by a number of issues, including neurological diseases such as multiple sclerosis and traumatic brain injury, and can result in communication difficulties in daily listening situations. A number of diagnostic protocols and management programs have recently been developed to address this population, based in part from interest in veterans returning from the Middle East with these types of disorders. Currently, there is no standard for assessment or rehabilitation of dichotic listening disorders. This study utilized a single-subject research design to address the potential effectiveness of a treatment program for dichotic listening difficulties. The subject presented with clinical deficits following a stroke, despite having normal hearing acuity. Auditory processing evaluation revealed severe deficits in the area of dichotic listening, most remarkably for the left ear. The patient was enrolled in the LACE<sup>TM</sup> (Listening and Communications Enhancement) program, a computer-based aural rehabilitation program developed to assist patients with hearing loss acclimatize to hearing aids. The program is designed to improve listening skills through use of an adaptive program that addresses a number of auditory processing skills. For this project, the LACE<sup>TM</sup> program was administered to this subject with headphones, to force binaural integration summation, and thus forcing the weaker ear to work, and not be reliant on the dominant ear. The results of the administration are pending, but so far the patient in question has attained sufficient improvement in listening skills, reducing the existing auditory processing and dichotic deficits. The success of this single subject design may help in guiding advancements in remediation of adults with auditory processing disorders.

## **Acknowledgements**

I wish to thank my advisor, Dr. Gail M. Whitelaw, for her continual support, direction, and extended efforts towards the completion of this project.

I would also like to thank Dr. Robert Sweetow, for his personal insight regarding the use of his program.

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## Chapter 1

### Introduction

When people think of hearing, they most commonly think of the ‘ears’ as having primary function of hearing. Actually, the ears are just the beginning of a larger unit responsible for the process of hearing. The mechanisms within the ear are only peripheral messengers for higher cortical structures within the central nervous system. These cortical structures then create the skills needed for successful listening, or adjusting the auditory system to adapt to the environment, by building neural pathways. Humans were designed with two ears, both of which function as modes for transforming sound waves into neurological signals, and then transporting these signals via neurological pathways in the brain to the auditory cortex, with the final destination being where comprehension takes place. Thus, listening is best achieved when both ears work together as a team (Whitelaw & Yuskow, 2005). Listening with both ears provides benefits beyond the recognition of sound, and may include localization of sound, auditory memory, and sound sequencing ability (Heasley, 1980). This phenomenon of a two ear advantage, or when both ears are working under ideal circumstances, is called the binaural advantage.

#### **1.1 The Binaural Advantage**

Binaural hearing describes the interaction and interplay between the two ears and the auditory pathways to the auditory cortex when adequate signals are presented to both ears. Thus, this presentation is referred to as the binaural advantage because it provides the brain with adequate signals, which makes it easier for the brain to understand and comprehend incoming

signals. The presentation of identical auditory signals to both ears is called diotic. A ‘real world’ application for this binaural advantage with diotic presentation is noted when speech signals, especially in noisy environments, are easier to understand when presented to both ears. This is independent of manual suppression switching, which is discussed in Chapter 2. This advantage occurs because a binaural, or “two eared”, presentation results in a favorable signal-to-noise ratio (SNR). The signal to noise ratio (SNR), or the relationship in decibels between the desired signal and its conflicting background noise, determines the degree to which the auditory system will be taxed, and will thus rely on dichotic skills. When the signal is not contaminated by such background noise, it can be processed easily by both ears, allowing for a clear and full auditory signal to reach the auditory cortex in the brain. Conversely, the presentation of two simultaneous differing signals to the ears is referred to as dichotic. When an environment has a poor SNR, competing signals tax the auditory system, forcing the use of dichotic skills, or the ability to discriminate differing signals. Dichotic skill performance is a component imperative to the understanding of the problems experienced by those with auditory processing disorders (APD), because an individual’s ability to distinguish a signal from noise is a skill which many with APD find greatly difficult.

## **1.2 APD and Dichotic Listening**

Central processing abilities refer to the efficiency with which the central auditory nervous system transfers information from the VIII nerve to the auditory cortex, and a Central Auditory Processing Disorder results from impairment in this function (Stach, 2000). It is also defined by the American Speech-Language-Hearing Association to include poor performance in one or more of a number of skills, including auditory performance in competing acoustic signals,

including dichotic listening skills (ASHA, 2005). When competing signals are presented to the ears, the result taxes the auditory system of the listener and forces him/her to use skills called dichotic skills, which are the basic skills that will be addressed in the scope of this thesis.

### **1.3 Etiology and Prognosis Overview**

In adults, there are a number of causes of an auditory processing disorder. These can include tumors or other space-occupying lesions within the peripheral and/or central auditory nervous systems, neurological diseases, and pathologies that damage central auditory structures or interrupt their blood flow, such as traumatic brain injury (TBI) or aphasia. Typical changes in brain function due to aging can also result in auditory processing disorders (Stach, 2000).

Recently, there has been a great interest in remediation of processing disorders, and specifically dichotic listening skills. Programs such as the Dichotic Interaural Intensity Difference training (DIID) (Musiek, Chermak & Weihing, 2007), and the Aural Rehabilitation for Interaural Symmetry (ARIA) program (Moncrieff & Wertz, 2008), have been developed to help alleviate the problems which impede a child's ability to perform in school, and negatively affect job performance and social relationships within adults. There are other types of auditory training programs currently available that are designed for purposes other than dichotic listening. One is LACE<sup>TM</sup> (Listening and Communication Enhancement), which is designed to help new hearing aid users adapt to their hearing aids by learning listening strategies that will help them make the most of the amplification devices. In terms of a treatment protocol, its ease of use and short program administration time may lead to better compliance from the listener. If a listener with an auditory processing disorder has complaints and complications similar to those



experienced by new hearing aid users, an auditory training program such as this may be an appropriate mode of treatment.

This study was designed to capitalize on current interest in treating auditory processing disorders in adults. A single subject research design was used to determine if a simple, commercially available auditory training program could enhance dichotic skills for an adult who lacks these skills, despite the program's design for other populations. The research questions are as follows. First, can using LACE<sup>TM</sup> (Listening and Communication Enhancement) program improve dichotic skills for an adult listener? Second, will use of the LACE<sup>TM</sup> program result in functional improvements?

## Chapter 2

### Review of the Literature

The term dichotic refers to different stimuli that are presented to the two ears simultaneously (Yost, 2007). Humans have two ears, which work together to send auditory signals via the auditory pathways to the auditory cortex in the brain. The two ears work optimally when signals from both ears are alike, and when there are minimal interaural time differences or sound shadow effects, due to the physics of sound and the physical location of the ears (Yost, 2007). Additionally, optimal processing occurs when the combination of the work of the ears sends adequate signals to the language dominant left side of the brain. It is only by this binaural advantage, or the two ears working together, that a listener will be able to take full advantage of hearing and processing auditory stimuli. Dichotic stimuli test the integrity of the hearing mechanism when in difficult listening situations. Additionally, dichotic listening describes how the two ears work together for optimal hearing, particularly in terms of localization and listening when background noise is present.

As mentioned previously, the binaural advantage can create optimal listening conditions in speech; however, the interworking complexities of the ear present circumstantial exceptions when an environment is not optimal for listening. For example, the process of attention may be manually switched to the other ear at will (Cherry, 1953). This actually increases the difference between the speech signals reaching the two ears, but in the process improves the speech to noise ratio (SNR), or the degree that a speech signal is audible in surrounding noise given any situation. As can be seen in noisy environments, it is the instinctive action to turn one ear toward the desired source of attenuation (Cherry, 1953). This is because dichotic conditions such as

these actually produce a release from high-frequency masking (Rand, 1974), or the ‘covering’ of speech which reduces the intelligibility or audibility of speech in the higher frequencies, such as consonant sounds. This type of masking is typical due to the physiological nature of the cochlea, or inner ear mechanism. Listeners who experience great difficulty with dichotic listening tasks, such as detecting signals and digits in noise, often have a hearing loss in only one ear, or the type of hearing loss in each ear differs drastically (Bellis, 1996). Therefore, unilateral and/or asymmetrical hearing loss that interferes with the connections between the ear and the auditory cortex, can lead to deficits in dichotic skills. Interestingly, as will be discussed more thoroughly later, this loss in dichotic skills can result from only a loss in auditory pathway connections, and not necessarily hearing acuity.

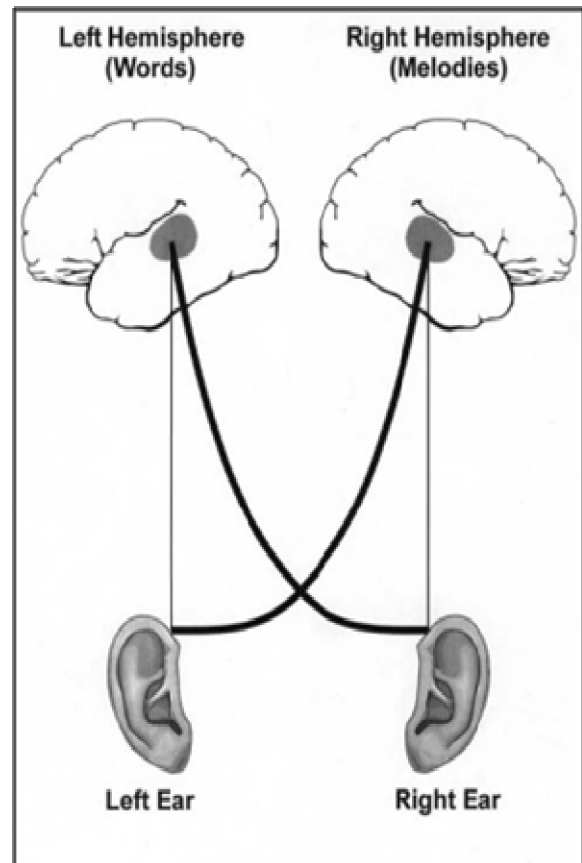
Interest in dichotic listening started initially within the field of psychology, which may not be surprising given the negative emotional and social aspects associated with processing disorders and dichotic skill deficits usually associated with an auditory processing disorder. In children, the impact of a processing disorder is palpable. Such a disorder can disrupt a child’s ability to develop verbal speech and language, and may also inhibit the ability to develop communicative social abilities. Within older adults, as will be the case within this study, it has been found that even small limitations in cognitive function negatively influence the quality of life, independence, frequency, and quality of social interaction, and engagement in cognitively stimulating activities (Mahncke, 2006).

More specifically, interest in dichotic listening research started with studies by Broadbent (Lachter, Forster, & Ruthruff, 2004), who first tested both ears simultaneously by using competing sets of digits while investigating the selective attenuation of stimuli. Broadbent’s studies were similar to the now commonly administered Dichotic Digits Test, and involved the

binaural simultaneous presentation of 3 pair digits to each ear from 1 to 10, excluding 7, because of its two syllable structure and thus different intelligibility. The listener is then required to repeat back all of the presented digits (Bellis, 1996). Other tests were later developed, and were based on these early research ideas.

## 2.1 The Right Ear Advantage (REA)

Doreen Kimura, a psychologist, and her colleagues were credited with first developing a dichotic speech testing technique to determine unilateral lesion effects and hemispheric asymmetry (Kimura, 1961). Kimura's model for evaluating dichotic listening skills involved a characteristic advantage in dichotic discrimination in the right ear for right-hand dominant listeners. Kimura found through her experiments, that when digits are alternated rapidly between the two ears, there is often a trend for the right ear to have superior performance over the left ear (Kimura, 1967). This



**The ipsilateral and contralateral auditory pathways (Kimura, 1961)**

phenomenon, referred to as the right ear advantage (REA), is thought to accurately predict said advantage based on the predicted strength of neural pathways thought to develop during language acquisition (Bellis, 1996). When an auditory signal travels through the central auditory nervous system (CANS), it encounters both ipsilateral and contralateral pathways. Kimura postulated the dominance of the right ear via the contralateral pathway to the language-dominant

left hemisphere of the brain (Moncreiff & Wertz, 2008). Within Kimura's experiments, she used stimuli to tax the auditory system of several right hemisphere-dominant listeners, and left-hemisphere dominant listeners. These subjects were determined by an administered digits test, similar to Broadbent's, which determined selective attention.

Her results suggest that the right contralateral pathway is more efficient for left-hemisphere dominant listeners, and that the left contralateral pathway is more efficient for right-hemisphere dominant listeners (Kimura, 1961). These results provide further support for the notion that the temporal lobe of the language dominant hemisphere of the brain is the most important in the perception of dichotic speech material, and that the contralateral pathways are always stronger than the ipsilateral.

When dealing with signals other than speech signals, the REA has an additional unique characteristic dealing with the function of the two hemispheres. The left hemisphere, as stated previously, has the tendency to show dominance for words arriving at the right ear (Kimura 1967). However, it is also important to note based on the results of experiments, the right hemisphere has predominance in melodic-pattern perception, and was identified by a heightened ability for listeners to identify melodies arriving at the left ear (Kimura, 1967). These factors of the REA discussed are only apparent in dichotic tasks, or other tasks that are equally taxing on the auditory system. They have become a significant foundation in the diagnostic assessment and treatment methods associated with deficits in dichotic listening skills.

## **2.2 Physiological Applications**

Dealing with the REA in more depth, another theory testing these pathways was presented later, and addressed the reasoning behind this noteworthy contralateral pathway

dominance. It was determined that the interaction between ipsilateral and contralateral information is influenced by both physiologic and acoustic factors (Sidtis, 1981). The physiologic factors may be due to a variability in the distribution of auditory fibers along the ipsilateral and contralateral pathways (Sidtis, 1981), and the resulting advantage of the dominant hemisphere may be due to the pathway that leads to its respective auditory cortex. Thus, this information may be important in understanding the etiology of a patient's disorder.

From a neurological perspective, temporal lobe lesions have the tendency to negatively affect the performance of the opposite ear due to the contralateral effect produced by the REA (Bellis, 1996). For example, a temporal lesion on the left temporal lobe will yield a difficulty in processing dichotic information from the right ear to the language dominant side of the brain. This temporal lobe lesion effect again reveals the strength specifically of the right contralateral pathway for language. If a lesion is located on the right temporal lobe, right ear extinction will not occur. This is due to the strength of the existing contralateral pathway to the language-dominant area of the brain. However, a left temporal lobe lesion will result in the patient's inability to process information through the left ear, and his or her perception that they have decreased hearing acuity in the left ear. Here, the auditory signal must cross through the contralateral pathway to the right lobe, then cross back to the language-dominant left hemisphere via the corpus callosum (Bellis, 1996). Resultantly, speech signals will not successfully arrive to the left hemisphere when confronted by a lesion of the left temporal lobe or the corpus callosum.

Additionally, if a lesion of the posterior corpus callosum is present, the patient will again show this unilateral deficit. Musiek, Reeves, and Baran (1985) showed how this is possible by investigation of split brain patients. These subjects underwent a surgery called a corpus callosotomy, which severs the corpus callosum, and temporarily interrupts the signal

transference between the two brain hemispheres. After severing the posterior portion of the corpus callosum, right ear performance improved while the left ear could not perform dichotic tasks. Conversely, severing of the anterior portion of the corpus callosum did not create a deficit when attempting dichotic tasks. It can then be concluded, that most auditory nerve fibers travel interhemispherically within the posterior portion of the corpus callosum (Bellis 1996). This again supports the notion that the right contralateral pathway is dominant when attempting difficult dichotic tasks.

The ‘site of lesion’ method for identifying a disorder within the auditory system is not always sufficient. The drive to find a particular ‘site’ where a single lesion may occur is in fact an oversimplification of the auditory system functions, and does not take into account individual differences of the listener (Whitelaw & Yuskow, 2005). Individual variability might appear as the addition of certain types of hearing loss, which may in turn affect the results of dichotic tests, despite any other present outstanding lesions. When given dichotic tests, patients with bilateral sensorineural hearing loss show significant advantages in either the right or left ear, according to an investigation by Roeser, Johns, and Price (1976). This hearing loss may affect the size or direction of the ear advantage. Conductive losses do not appear to have major affects on dichotic listening tasks, assuming both ears are equally affected by the conductive loss (Bellis, 1996). It is also possible for the listener to have normal peripheral hearing sensitivity, and for the only problems to exist to be within processing skills. Such will be the case for this particular study, and the emphasis will be on clinical testing and remediation techniques.

## **2.3 Clinical Applications**

Early intervention into dichotic listening from a research perspective moved into the clinical realm in the 1960's. Since this time, the interest has expanded with recent and continual growing attention to the clinical intervention of Auditory Processing Disorders (APD). Since dichotic skills are an integral player in the determination of APD, the appropriate assessment tests are discussed.

Evaluation to determine the presence of an auditory processing disorder may include a variety of measures, and should be tailored to the patient's specific needs. Ultimately, the determination of sensitivity or specificity of APD is dependent on the functional effect of auditory deficits, given that the heterogeneity of the disorder leads to no true gold standard (Bellis, 2006). The behavioral APD test battery may include tests to determine temporal processing, monaural speech, localization and lateralization, binaural interaction, and dichotic stimuli (Masters, Stecker, & Katz, 1998). Monaural methods of testing include stimuli presented to only one ear. These include the word-recognition score, which uses speech signals to determine the speech threshold of comfortable listening, and creates a ratio representing the best speech understanding that can be achieved in the test ear (Stach, 2000). The binaural auditory system is a great detector of differences in timing of sound reaching the two ears, and with tests such as the Masking Level Difference (MLD) test, can determine the ability of the ears to release from the masking caused by the interaction of the two ears in receiving auditory stimuli (Stach, 2000). Developing a test battery to assess auditory processing skills would incorporate a range of monaural and dichotic listening tasks. The idea behind the auditory processing evaluation is to "tax" the system, to challenge it to listen, as happens in actual listening situations. The concept



is to assure that the auditory system is challenged or taxed in order to assess the flexibility of the system and to determine the function of that system in adults.

The diagnostic testing for dichotic skills is included within the test battery to determine an auditory processing disorder, and such testing determines the patient's ability to either integrate the auditory information presented to both ears concurrently, or the patient's tendency to divide the information into separate signals. Essentially, these tests can provide information regarding neurotransmission of the Central Auditory Nervous System (CANS), minus other alternative factors such as attention and motivation. This in turn makes it easier for an audiologist to rule out the possibility of a language or speech disorder, and diagnose a potential processing disorder which is isolated primarily in the auditory system. (DeBonis & Moncreiff, 2008). The methods of testing involve the presentation of stimuli that strain the auditory system, such as competing noise, Dichotic Digits, and Dichotic CV nonsense syllables (Bellis, 1996). A reduced performance with such tasks may correlate to situations within the patient's everyday life, such as difficulty attending in a group or noisy settings, and difficulty attending to one piece of information while attending to another (DeBonis & Moncreiff, 2008). The results of these dichotic tests may be consistent with a pathological condition within the auditory pathway.

A patient with a known lesion of the auditory system will often express a unilateral deficit during dichotic listening tasks, because the two ears work best together, and thus need bilateral stimulation to work to their best ability. Because of this insufficient ability in dichotic listening, the patient will find it particularly difficult to discriminate speech from noise in daily listening situations despite normal hearing acuity. For example, in some situations, the patient will be able to hear the words spoken to them, but will not be able to understand said words, particularly in less than optimal listening situations, such as in a restaurant or classroom when

background noise is present. It is important to note that a normal audiogram despite these listening issues is a trademark symptom of an auditory processing disorder, and oftentimes will lead to the disorder being overlooked, because those with sensorineural hearing loss typically experience these same symptoms. In this case, a possible misdiagnosis can result in even greater frustration for the patient. Therefore, it is especially important that an audiologist be competent enough to recognize these symptoms and give a differential diagnosis of APD. This differential speculation, when given by a clinician competent in the physiology of the auditory mechanism, will most likely lead to a more effective prognosis.

## **2.4 Assessment Techniques and Identification of APD**

A processing disorder can only be truly diagnosed after a comprehensive battery of dichotic tests have been presented by an audiologist. If a listener shows difficulty with a wide variety of tasks, then it would be determined that the patient's problem is one more global in nature. However, if the listener expresses difficulty with only auditory based tasks, it can then be concluded that a 'pure' auditory processing disorder is present (DeBonis & Moncreiff, 2008).

Testing to determine the presence of an auditory processing disorder is achieved through either electrophysiologic testing measures, which use specialized equipment to determine the presence of a lesion along the auditory pathway, or by the use of behavioral tests, which use the response of the patient as compared to norms from other patients to determine a disorder. Both of these methods are typical to use with adults, and the challenge associated with these tests is the goal of quantifying functional difficulties of the patient that appear in a behavioral form.

Behavioral dichotic testing techniques differ greatly in their presentation methods, but all are aimed at achieving one of two binaural tasks. Binaural integration requires the listener to use

the relationship of the two ears to repeat everything that is presented. An example of this is the Staggered Spondaic Word Test (SSW; Katz, 1985). This test protocol involves the presentation of spondees, words that are relatively linguistically equal in their formant weight, in such a way that the second syllable of the first word overlaps the first syllable of the second word (Martin & Clark, 2008). The patient is required to repeat back both of the words in the order they were presented. An inability to integrate the connection between the two ears in this task may suggest an interruption or lesion along the auditory pathways. The second of the binaural tasks is binaural separation, which requires the listener to attend to and repeat what is heard in only one ear (Bellis, 2002). The Competing Sentences test is a commonly used separation task, and requires the listener to repeat back only one of the two differing simultaneous sentences presented to the ears. An inability to separate acoustic stimuli in this task means the patient may be reliant on one ear due to a potential weakness in the processing along the pathways coming from the other ear.

## **2.5 Prognosis**

Once an auditory processing assessment is completed, it is possible to determine if an auditory processing disorder is present, along with ear involvement and severity of the problem. Obviously, most patients are interested not only in being able to define the problem but also being able to identify approaches to manage or treat the disorder. Traditionally, auditory processing disorders have been addressed in a three pronged approach 1) environmental modifications , such as changing the listening environment in terms of seating, acoustics, etc. 2) compensation strategies, such as note taking strategies, using “tricks” for organizing auditory information, lip reading, etc., and 3) direct treatment, focused on changing the auditory system

(Ferre, 2006). Historically, the focus has been on management strategies that address environment modification and compensation. This suggests that although auditory processing disorders may not be considered to be “curable”, the problems associated with these disorders can be greatly decreased with the application of neural plasticity, once an accurate and complete assessment is complete (Ferre, 2006).

## **2.6 Frequency Modulated (FM) Systems**

An effective means of maximizing a listener’s environment through compensatory strategies is through the use of an FM (frequency modulated) system. There are a variety of systems, and they ultimately use a type of microphone to minimize the SNR, and to provide benefit in situations where understanding is difficult with hearing amplification alone, such as an educational setting, or while making calls on the phone ([www.Phonak.com](http://www.Phonak.com)). The most commonly used signal-enhancement approaches include the provision of either a personal FM system, or a classroom/group amplification system, which reduces extraneous or competing environmental noise through the amplification of sound attenuating materials in the listening environment (Baran, 1998). Conversely, the other form of signal-enhancement is the use of a sound field system, which serves a large group of people more like a public address. Sound field systems are designed specifically to ensure that the speech signal, in its entirety, reaches all the listeners in a room (Flexer, 2007). Ultimately, the goal of either of these systems is to effectively provide a high-quality acoustic signal and reduce the effects of background noise and reverberation (Stein, 1998). These systems produce an



**Phonak iSense Micro**

environment with an improved SNR, and therefore improve the efficiency of learning for children through the integrity of acoustic signals.

However, it must also be noted that the prognosis is good for adults who can overcome issues of rejection relating to the instrumentation for self esteem and peer acceptance reasons (Baran, 1998). It is also important to mention that new technologies, such as the iSense from Phonak, have been designed to look similar to other popular technology devices, and thus may help overcome peer acceptance or emotional incompetence issues. Additionally, it is the job of the audiologist to realize that the needs of a mature individual are different from a child, whose main job is typically that of a learner. Adults may need attention brought to job effectiveness, community involvement, family relationships and parental effectiveness, all of which can be negatively affected by APD (Baran, 2002). A mature individual may also experience a wider variety of behaviors in differing contexts, which may lead to difficulties in consistent functioning for FM devices (Baran, 2002). These issues are important for an audiologist to consider when developing a remediation program in order to enhance the environment of the listener through the improvement of the SNR. With a more adequate SNR, a listener has better access to speech signals, and the probability of successful communication increases.

## **2.7 Direct Treatment**

Recently, a greater focus has been put on the actual treatment of auditory processing disorders. This effective management is achieved through cortical reorganization of neural substrate, thought to be possible because of the phenomena known as neural plasticity. In general terms, the plasticity of the brain refers to the property which allows neural connections to grow stronger, and ultimately it refers to the brain's lifelong capacity for physical and functional

change. Typically, the brain's ability to build these neural connections decreases with age. That is, the likelihood for one to achieve the significant changes in neural forms and connections needed for auditory processing skills decreases as one matures (Baran, 1998). Even with this being the case, the prognosis for an adult with APD is not a lost cause. Rather, it must also be considered that plasticity is the capacity that allows experience to encourage learning throughout life (Merzenich, 1993). The pathology of the central nervous system allows constant 're-building' of its pathways, because it is the nature of the brain to try and overcome functional neurological boundaries (Phillips, 2002). It is up to the audiologist to encourage this learning through compensatory strategies and direct remediation.

Direct treatment is an option when a particular skill, such as dichotic listening, needs improvement, and a method for researching neural plasticity potential is available. This property is essential to understanding remediation methods for dichotic tasks because the synaptic changes thought to be created within the central nervous system, due to changes in stimulation, are those responses most essential to learning (Hebb, 1949). In other words, neural plasticity is the reason a listener can effectively be taught the ability to perform dichotic tasks. To achieve this result, a training procedure must be developed which taxes the auditory system.

The most efficient types of training for processing disorders are plasticity-engaging, and resultantly can enhance the cognitive-function in normal mature adults (Mahncke, 2006). However, it must also be considered that the degree of neuronal change and maturation is dependent on the quality and consistency of stimulation, bringing forth issues discussed earlier relating to FM amplification systems (Chermak & Musiek, 2002). If the specific deficit involves dichotic skills, therapy may involve dichotic listening training programs, in which the intensity levels for each ear are gradually adjusted to improve the listener's performance in the weaker ear

(Bellis, 2002). Dichotic listening training procedures are typically designed to enhance either binaural integration, or binaural separation. Within integration training, the listener is required to attend to both simultaneous differing targets presented to each ear. Conversely, separation training involves the listener's ability to attend a signal in one ear and ignore the opposite signal (Ferre, 2006).

Other training procedures use an approach unique to manipulating the intensity differences between the competing signals. A study of split-brain patients, or those that have undergone a corpus callosotomy procedure, conducted by Musiek concluded that the strategic manipulation of interaural intensity differences between the two ears could alleviate auditory processing deficits. This result could most especially be seen when the Dichotic Digits Test (DDT) was administered (Musiek, Chermak & Weihing, 2007). Since this publication, new training programs have been developed which build off of this therapy protocol. Specifically, when put into dichotic circumstances such as the Dichotic Interaural Intensity Difference Training (DIID), the training attempts to strengthen the weaker pathway by capitalizing on these intensity differences (Musiek, Chermak & Weihing, 2007). Another essential aspect of auditory training involves the modification of stimuli in order to maintain an adequate degree of success, or the targeting of specific stimuli to improve processing in a successive manner, while providing a challenge for the listener which will ultimately tax, but not exhaust the auditory system. (Musiek, Shinn, & Hare, 2002). Tasks that are too easy or too difficult will not result in efficient treatment; therefore an adaptive task is required in order to target the most effective stimulus.

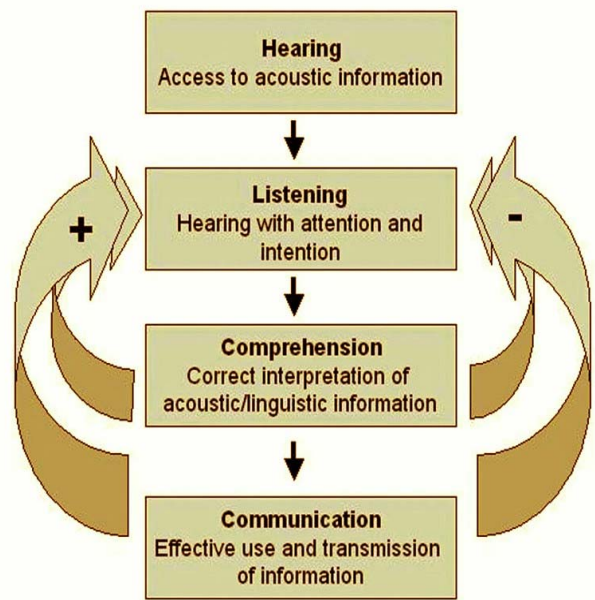
When put into practice, these therapy approaches are successful because they tax precise areas of the cortex, which in turn forces the auditory pathways to these areas to exercise and

build strength through neural connections. It is also thought that decreasing the intensity level of the presentation to the better ear may release the weaker pathways of the ailing ear, allowing neural substrate to most effectively be activated as the difference in intensity is maximized (Musiek, Chermak, & Weihing, 2007). As the integrity of these pathways is improved, speech stimuli can more effectively reach the language processing temporal lobe, and dichotic skills become better. Although these tasks may seem appealing due to the scientific basis backing the prognosis of a patient, these tasks are often time consuming for both the patient and audiologist, making them difficult to effectively complete as planned, and may lead to fatigue or loss of attention for the patient.

For example, the current focus on neural plasticity training has resulted in training programs, including the two previously mentioned Dichotic Interaural Intensity Difference training (DIID) (Musiek, Chermak & Weihing, 2007), and the ARIA program (Moncrieff & Wertz, 2008). Although the integrity of these programs is strong, they both must be administered by audiologists trained specifically in these programs. Additionally, the listener is required to come to 5 sessions per week administered in a clinical setting, often for many weeks, and the materials may not be interesting to the listener, meaning they may not capitalize on the neural plasticity in an adult brain.

## 2.8 LACE™ (Listening and Communication Enhancement)

Training the auditory cortex of the





brain is an important step in strengthening the auditory pathways coming from the ears in much the same way that physical therapy strengthens adjacent muscles and leads to physiological adaptation (Sweetow & Henderson-Sabes; 2004). In particular, a home-based personalized training program designed for hearing aid users called LACE<sup>TM</sup> (Listening and Communication Enhancement) works to manage deficits reported by people with peripheral hearing loss once they are fit with hearing aids. The program is not designed to improve hearing acuity per se. Rather, through a variety of adaptive tasks, LACE<sup>TM</sup> integrates skills that are imperative to successful listening, including intention, attention, understanding, and remembering (Sweetow & Henderson-Sabes; 2007). Sweetow's schematic, seen above, shows how theoretically, an inability to communicate or comprehend always leads back to some kind of deficit in listening skills.

People with peripheral hearing loss who utilize hearing aids sometimes struggle to adapt to their devices because the hearing aid may simply make sound more audible, without addressing issues of frequency and temporal resolution, undesirable acoustic conditions, or acquired compensatory strategies, issues thought to be related to the “processing” of auditory information (Sweetow & Henderson-Sabes, 2004). LACE<sup>TM</sup> uses auditory tasks to address these situations or difficulties. The adaptive tasks within the program are divided into three main categories: degraded speech, cognitive skills, and communication strategies (Sweetow & Henderson-Sabes, 2007). The degraded speech exercises comprise 70% of the tasks, and include time-compressed speech, speech in babble noise, or a single speaker (Sweetow, Henderson-Sabes, 2007).

This individualized training is thought to work, in part, because the program is adaptive. In other words, the difficulty of the training at all times remains close to the subject's threshold

for the task, even as that threshold changes (Sweetow & Henderson-Sabes, 2004). Therefore, the training accelerates and makes the acclimatization of the brain to these multiple hearing tasks possible (Sweetow, Henderson-Sabes; 2004). In other words, the program utilizes neural plasticity to adapt the brain to successfully complete these tasks, and ultimately improving communication capability. Since these are all tasks typically difficult for a patient with an auditory processing disorder, it seems probable that this program would be able to help a patient with APD improve auditory listening skills and overall communication effectiveness. The program does not address dichotic listening skills directly, but the nature of the training modules may help a subject who has these difficulties. Currently, LACE™ is available from Neurotone, a company that, “builds quality media enhancement and aural rehabilitation solutions” ([www.Neurotone.com](http://www.Neurotone.com)). The program can be downloaded from a website for personal use. Additionally, an audiologist can log into the site securely to view the progress of a listener.

#### **3.1 Subject**

A single subject research design was used for this study. A patient presented at the Ohio State University on 4/24/09. This subject whose characteristics will be described below, has an auditory processing disorder. Although patients with auditory processing disorders share characteristics, they are often very heterogeneous in their presentation. This was the basis for the single subject research design. A single subject design allows for greater attention to detail, which was ideal for this particular subject and his disorder. Experimental designs that differ from this, such as group statistical analysis, run the risk of losing important patient attributes within the pool of subjects (Barlow & Hersen, 1973). Obviously, this design will not answer all possible questions. This study is designed as a preliminary look at the potential benefit of a listening program on dichotic skills.

As noted above, the subject was recruited from the Ohio State Speech-Language Hearing Clinic. He is a 32 year old male with a history involving seven concussions over the course of his lifetime, and high levels of occupational noise exposure due to combat experience in the military, though adequate hearing protection was reported. This subject had a stroke on 2/19/08 thought to have resulted from a blood clot originating from a small hole in his heart. Initially, the subject was paralyzed on one side of his body and was unable to speak. Since the stroke, the subject received rehabilitation services, including speech/language therapy services at Dodd Hall Rehabilitation Hospital at the Ohio State University. Since this time, and the initiation of this study, he has recovered most of his pre-stroke language skills, based on self report, and has

recently been able to return to work. Balance issues and tinnitus in the right ear were also reported, as well as sounds being “muffled” in the right ear. Both speech perception and speech production were initially reported as difficult for the subject. He originally sought out a hearing evaluation because he reportedly perceived a decrease in hearing in his right ear.

A comprehensive audiologic evaluation performed on 4/24/09, revealed normal peripheral hearing acuity bilaterally, with normal middle ear functioning for both ears. An auditory processing battery was also performed on the subject, with results of the audiologic and auditory processing evaluation in Appendix A. The results from an auditory processing test battery were consistent with the presence of a severe global auditory processing disorder, most specifically for the right ear. The subject particularly struggled with dichotic types of listening skills most especially in the right ear, and sometimes in both ears. Because of this diagnosis, the patient demonstrated deficits of only a minimal severity in optimal listening conditions. However, when presented with complex listening stimuli, which include those with a poor SNR, the patient struggled significantly. The lack of dichotic skills impacted the subject’s ability to communicate effectively, particularly when background noise was present. Additionally, he reported depression within the time period following his stroke.

The subject initiated this treatment on 4/24/09, following signing the research informed consent. At that time, the subject had recently started back to work, as he demonstrated signs of increased function. Subjectively, the subject reported the use of compensatory strategies, such as lip reading, which had made it easier for him to communicate in difficult listening situations.

### 3.2 Treatment

As described in chapter 2, LACE<sup>TM</sup> (Listening and Communication Enhancement), is an auditory listening enhancement program. The program was administered as a direct remediation method for the subject's auditory processing difficulties and dichotic listening disorder. The subject was registered into the secure internet site to allow his access to the program. Currently, there is no standard for assessment or rehabilitation of dichotic listening disorders, but those who typically use LACE<sup>TM</sup>, such as new hearing aid users, experience similar problems with listening in complex or competing signal environments. Therefore, this program was administered with the intention of helping the patient strengthen listening skills, and also to help in guiding advancements in remediation of adults with auditory processing disorders.

The majority of the program contains degraded speech exercises, in which speech is presented with background noise, with a single competing speaker of male, female, or child voice, and a simulation of rapid speech through time-compression. The subject listens to a sentence or phrase, and then tries to correctly identify the sentence. If the subject claims to have understood the exercise, the next sentence will be given with more difficulty. Either the SNR will be less favorable, or the time-compression increased (Sweetow, & Henderson-Sabes, 2007).

The other sections of the program involve the development of cognitive skills and communication strategies. The section devoted to cognitive skills focuses on listening skills that are helpful when in noisy environments, such as auditory memory and the speed of processing. These tasks may include a missing word from a phrase which the subject is then required to provide, or the task will require listening for a specific word, and identifying key words surrounding that target word. The communications strategies section includes tips and coping strategies for communication environments that are less than desirable. The purpose of this

section is to give the subject advice over time, rather than overwhelm him or her with multiple suggestions at once (Sweetow, & Henderson-Sabes, 2007).

Additionally, for the purpose of this single subject case study, this program is preferable over other programs such as the DIID or the ARIA. LACE™ allows more flexibility in the patient's time schedule, as it can be administered at any time of day, and can also be administered at home. Additionally, the majority of the program's benefit is typically experienced after the completion of the first 10 training sessions ([www.Neurotone.com](http://www.Neurotone.com)), and the listener's results can be tracked online by the audiologist, making it easy to monitor progress. These factors make the program more desirable for the patient, meaning that they are more likely to actually complete the training. Lastly, LACE™ is designed specifically to keep the attention of listeners with different subjects or lectures of conversation and speech. This not only prevents fatigue or boredom for the listener, but it also increases the chances that they will continue using LACE™ and maximize their ultimate communicative benefit from the program. Even though these assets make LACE™ preferable for a subject, it can also be more difficult for an audiologist to control than a center based type of program. For example, monitoring the type of headphones used by the subject, or the consistency with which the subject maintains the training is difficult.

### **3.3 Procedures**

The LACE™ program was administered based on standard protocol described by Neurotone.com ([www.Neurotone.com](http://www.Neurotone.com)), which suggests training to take place over a four week period for 30 minutes 5 days a week. The treatment is designed to be a patient-administered program over the internet by the subject logging onto the secure site. The program is designed to

be utilized by listeners through “standard” headphones presented via a personal computer. The initial volume level was manually set by the subject, and the program automatically changed volume throughout the exercises to adapt to ability. The program is designed to be administered for 20 days over a one month period. The instructions for the LACE™ program were reviewed with the subject by the researcher, including the importance of completing the prescribed number of sessions in the appropriate timeframe. The ability to monitor progress was described to the subject. It was also explained that the researcher would be able to monitor his progress through an independent secure web connection.

## Chapter 4

### Results

Due to several extenuating circumstances, the subject was only able to complete 6 LACE™ sessions within an allotted 2 week time frame. Despite this, he showed great improvement in the LACE™ program statistics, as shown in appendix B, and as will be expanded upon further. All the LACE™ degraded speech exercises were given at the most comfortable level (MCL), and thus automatically adapted to the patient's ability during progression of the program.

#### **4.1 LACE™ Data**

Within the LACE™ training program sessions, the subject showed sufficient improvement, especially in speech in noise related tasks. All of the data collected within the LACE™ program can be found in appendix B. The speech in noise degrading speech exercises portion of the program automatically adapted to his skill level by improving or worsening the speech to noise ratio (SNR) based on his responses. Over the many answers recorded during the 6 training sessions, the subject needed progressively less of a dB increase in order to hear speech signals in the presence of complex background noise. This overall decrease, as seen in appendix B image 1, indicates an improvement in these tasks.

Additionally, the degraded speech exercises included competing speaker tasks, in which the listener was presented with two simultaneous sentences of differing content from different speakers. The sentences were presented to both ears, thus forcing binaural integration. This did not allow the subject to rely on one ear over the other, as was the case before remediation, and



thus was receiving adequate signals to the auditory cortex. The data acquired from this portion of the LACE™ program is displayed in appendix B image 2. A hypothetical decrease for this task would indicate an improvement, as less of a dB boost would be needed in order for the subject to hear one sentence over the competing sentence signal. The subject had fluctuating responses for this task. The reason for this was most likely due to the adaptive nature of the task, and the fact that he had not yet completed enough of the program to show any sign of improvement. Despite the subject's fluctuating scores for the competing signals task, it had likely value, as it most likely helped prepare the subject for post training tests within the auditory processing battery.

The last section of the degraded speech tasks involved rapid speech exercises that were designed to help the listener process incoming information with greater speed. The process for this task was simplistic. The speed of the speaker was increased until intelligibility was no longer possible, or the speed was decreased if a passage was too difficult. The graph representing the subject's performance on this task can be found in appendix B image 3. An increase on this graph represents an improvement. The subject initially improved his speed ability to twice the original speed, and remained within the vicinity of 2x for the remainder of the training.

The word memory task, a portion of the cognitive skills tasks within LACE™, required the listener to remember a 'target word' provided before hearing a sentence. After the sentence was heard, the listener was asked to identify a word placed either before or after this 'target word'. The score range for this test was between 1 and 6, with 6 indicating excellent word memory. The subject's scores ranged between 1 and 3 throughout the 6 sessions completed. A graph of this training is located in appendix B image 4. Additional training may have lead to more conclusive results for this task. Based on the post test scores on the auditory processing battery, this task may have prepared the subject for the SSW and Competing Sentences test.

## **4.2 Auditory Processing Battery Test Data**

Upon the subject's completion of 6 LACE™ sessions, an auditory processing battery was performed again, with numerical results of the audiologic and auditory processing evaluation in Appendix A. Additionally, it is important to note that the pre test scores were taken a year previous, and the same pre test scores resulted a year later, on 4/24/09. Thus, the post test scores taken on 5/08/09 with similar tasks, demonstrated improvement after completing the 6 LACE™ sessions within 2 weeks.

The competing sentences task showed no change from the pre test scores taken two weeks previous to the post test. It is best postulated that the competing speaker portion of LACE™ was beneficial despite these results, as the subject's linguistic awareness was heightened, and he was sometimes able to repeat back the last word from a sentence. It is important to note that this test requires 100% word accuracy in order to receive credit for an answer. In other words, the 'all or nothing' scoring nature of the test was not lenient enough to catch some of the behavioral changes displayed by the subject, such as the ability to repeat back some of the words in a sentence.

Post test scores were additionally taken for the Staggered Spondaic Word Test (SSW), which tests for binaural integration ability. This test revealed a sufficient improvement in identifying words when presented as dichotic signals, with an especially noteworthy improvement for tasks requiring the right ear to identify words.

Overall, the post test results for the auditory processing battery showed a sufficient performance improvement in dichotic tasks, most especially for the right ear. The subject is still diagnosed as having an auditory processing disorder consistent with normal hearing acuity, but the severity of the disorder has decreased. The subject is now able to achieve tasks he struggled

with previously, and the subject's self report revealed that he could once again "hear" out of his right ear when presented with dichotic tasks. Most importantly, his ability to process sounds in conflicting acoustic situations has improved, which will lead to an enhancement in his overall communication ability.

## Chapter 5

### Discussion

The results from an auditory processing test battery revealed a major improvement in speech in noise related tasks. The subject's test results changed from a moderate disorder classification for this task, to a mild disorder classification. These scores, which may have changed due to the LACE<sup>TM</sup> speech in noise training tasks, indicated that the subject will better be able to hear and understand speech when in complex background noise.

### 5.1 Theory

The original goal for the treatment of the subject's dichotic listening disorder was improvement in the areas of auditory processing that were at the time inhibiting adequate communication. It can be postulated that the subject's difficulties were likely related to a disruption within synaptic connections along the contralateral auditory pathway leading from the right ear to the left auditory cortex, where language is dominantly perceived and comprehended, or, a lesion within either temporal lobe of the brain which disabled the subject's ability to summate incoming signals. This disruption or lesion resulted in the lack of comprehension or understanding of stimuli, because this brain area was only receiving signals from one ear, or from one of the two speech signal messenger team members. The speech processing system, or team, was weak because it was not practicing with all of its available players. Just as the brain needs two ears to listen adequately, a rowboat needs two rowers. If one rower stops rowing, the boat will still move, but it will lack direction and efficiency.

Hopefully, the processing disorder would show signs of improvement through the strengthening of the contralateral auditory neural pathway from the right ear to the language

dominant left side of the brain or the strengthening of the left temporal lobe processing area for speech signals. The training program LACE™ was chosen as a direct treatment method for the listening skill disorder, with the intention that binaural integration signals presented over two headphones would force the subject to listen with both ears (Sweetow, 2009). Ideally, this binaural summation would force the right ear to practice using the contralateral pathway to the language dominant hemisphere of the brain. Given that the right contralateral pathway is postulated to be the strongest connection to the area for language (Kimura, 1961), the hopeful re-establishing of synapses along this pathway, due to neural plasticity, would give this area of the brain access once again to signals via both ears. Thus, the brain could again practice receiving signals from two players, and their teamwork would lead to better processing and understanding of auditory signals.

## **5.2 Linguistic Closure and Compensatory Strategies**

The cognitive skill strategies within the LACE™ program, mainly the word memory exercises, may have prepared the subject for tasks within the auditory processing battery test which required the application of similar skills. Particularly, it should be noted that the subject expressed a heightened awareness for words within the competing sentences test, and was sometimes able to repeat back particular words. Interestingly, this ability seemed to appear when the particular word of a sentence was somewhat expected due to its surrounding words or context. This ability to use linguistic closure to determine contextual information may not only show the application of skills practiced within the LACE™ program, but it may improve the subjects overall communication abilities and competencies within everyday conversation.

It should additionally be reported that the subject gave account, after the use of LACE™ sessions, of easier application of compensatory strategy skills, most especially lip reading. Although unrelated to the perception of auditory stimuli, this compensation strategy has the potential to help the subject with communication abilities until further treatment is given.

### **5.3 Conclusions**

It can be observed from the data acquired in both the LACE™ program tasks, most especially the degraded speech exercises, and the post test auditory processing battery, that the subject is showing improvement in dichotic related tasks. It is especially important that these improvements were apparent when considering the time constrictions and multiple extenuating circumstances that prevented the subject from using the program to its greatest potential. It can be postulated that these improvements in dichotic skills were due to re-establishing synaptic connections along the auditory pathways leading to the auditory cortex on the left side of the brain, and the forced exercising of this cortex to process auditory signals with two adequate signals via both ears. Additionally, it can be hypothesized that this binaural practice might have reminded the possibly damaged processing auditory cortex how to better use these incoming signals together, like two players on a team, to process and understand speech stimuli.

### **5.4 Alternative Explanations**

It must also be considered what additional considerations may have influenced the subject's processing skills. As stated previously, he did receive speech/language therapy prior to using LACE™, and it is possible that the reestablishment of language improved his chances of successful treatment with LACE™ because acquiring language is itself a partially auditory

process. The language acquisition may have redistributed the auditory fibers along the auditory pathways, and thus influenced particularly important physiological properties of these pathways (Sidtis, 1981). It must again be urged, however, that the pre test scores on the auditory processing battery were taken both before the training began and one year previous. Therefore, it may be the case that the dichotic skill improvement happened only during the two weeks of the LACE<sup>TM</sup> training, and was not influenced by other factors during this specific period.

Additionally, the subject eagerly awaited this treatment program, and thus it is possible that the initiation of training caused the subject to think he was indeed improving. This competence may have well equipped his attitude towards the effectiveness of LACE<sup>TM</sup>, and thus may have made him more likely to experience improvement.

## **5.5 Continued Study**

A single case study design was optimal for this study because it allowed such close attention to behavioral detail, which is imperative in a study where the nature of the disorder yields such great variability in skill. Future study with group designs may be appropriate to further determine the effectiveness of LACE<sup>TM</sup> on those who have auditory processing disorders and lack dichotic skills. A group design study would allow for comparisons of LACE<sup>TM</sup> to other forms of listening treatments, such as the DIID training program (Musiek, Chermak & Weihing, 2007), or the ARIA training program (Moncrieff & Wertz, 2008). Such comparisons might determine which modes of treatment work most effectively, and more specifically what aspects of these programs provide the best remediation for different populations that lack processing skills. Additionally, group studies may be ideal for investigating potential long-term effectiveness of LACE<sup>TM</sup> in individuals with APD,

## 5.6 Final Reflections

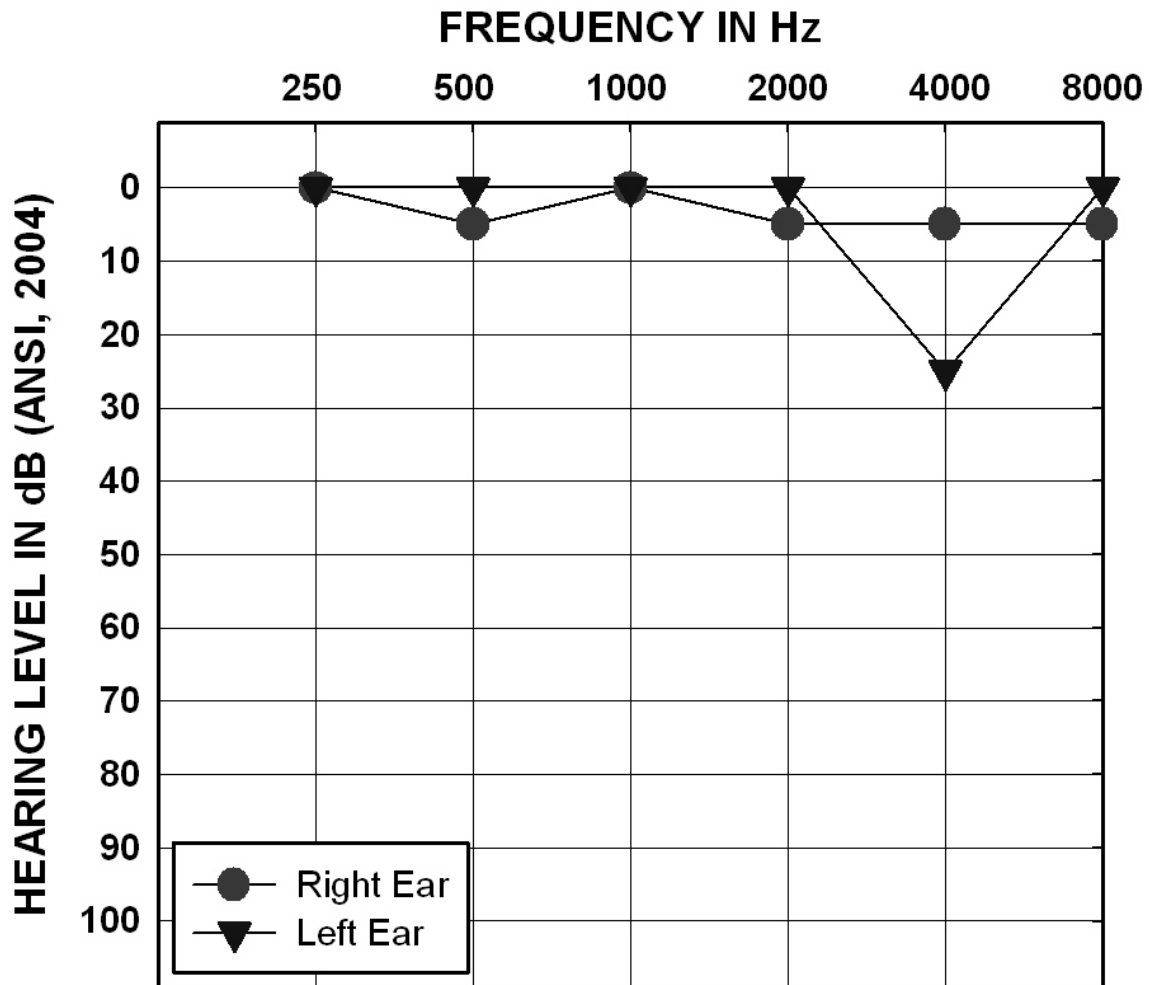
In reference to the original questions presented in this study, the training program LACE<sup>TM</sup> appeared to improve dichotic skills for an adult listener. This can be seen through the LACE<sup>TM</sup> training data, the auditory processing battery test data, and by the personal improvements reported by the subject. In terms of functional improvements, the subject appears to have improved his ability to “hear” dichotic signals presented to his right ear, and enhanced compensatory strategies have helped his competency in day-to-day communicative situations. Further study using LACE<sup>TM</sup> should be continued on this population, given the heterogeneous symptoms and behaviors associated with dichotic listening disorders, to determine the versatility and stability of the training benefits. It may also be helpful to develop a timeline for training protocol for given subjects. Prior knowledge and commitment to the LACE training on a regular basis may further secure the probability that the subject will complete the training sessions. Based on this study, a commercially available training program designed for the enhancement of listening skills, can be used as a treatment method for an adult with an auditory processing disorder expressing dichotic deficits.



## Appendix A

### Auditory Processing Battery and Audiometric Test Data

Audiogram for the subject in question:



This audiogram shows hearing acuity within a normal range, 0-25dB, for both ears.

## Appendix A

### Auditory Processing Battery and Audiometric Test Data

<b>Auditory Processing Battery Tests</b>	<b>Pre-Test Scores</b>	<b>Post-Test Scores</b>	<b>Comparison to Norms</b>
1. Staggered Spondiac Word Test (SSW)	# Missed	# Missed	
R Non Competing	20	10	Normal for adult $\leq 1$
R Competing	38	26	Normal for Adult $\leq 2$
L Non Competing	8	5	Normal for Adult $\leq 4$
L Competing	4	2	Normal for Adult $\leq 1$
2. Quick Speech in Noise (QSIN)	SNR Loss	SNR Loss	
	8.0 SNR	4.5 SNR	Normal for adult is situational: 1-2 SNR loss
3. Competing Sentences Test	% Correct	% Correct	
Right	0%	0%	
Left	100%	100%	

#### 1. Staggered Spondaic Word Test:

This test revealed a sufficient improvement in identifying words when presented as dichotic signals, with an especially considerable improvement for tasks requiring the right ear to identify words

#### 2. Quick Speech in Noise:

A major improvement in speech in noise related tasks can be seen from these test results. Diagnosis for this task changed from a moderate disorder classification to a mild disorder classification.

3. Competing Sentences Test: No change, but linguistic awareness was heightened. The subject was sometimes able to repeat back the last word of a sentence.

Appendix B  
LACE™ Training Data

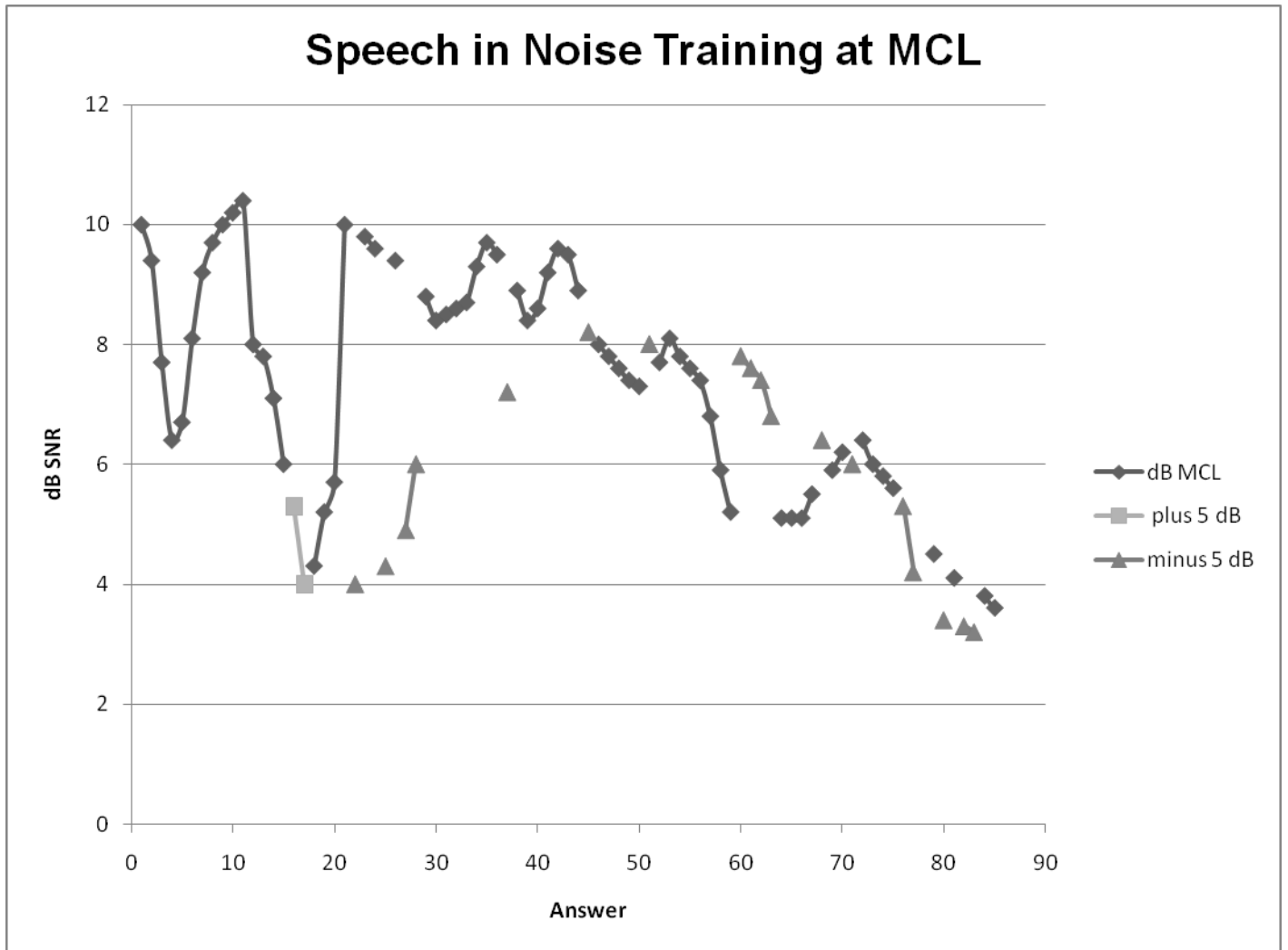


Image 1: Data as gathered from the speech in noise training tasks in LACE™. A decrease indicates an improvement in the ability to understand speech signals in the presence of noise.

Appendix B  
LACE™ Training Data

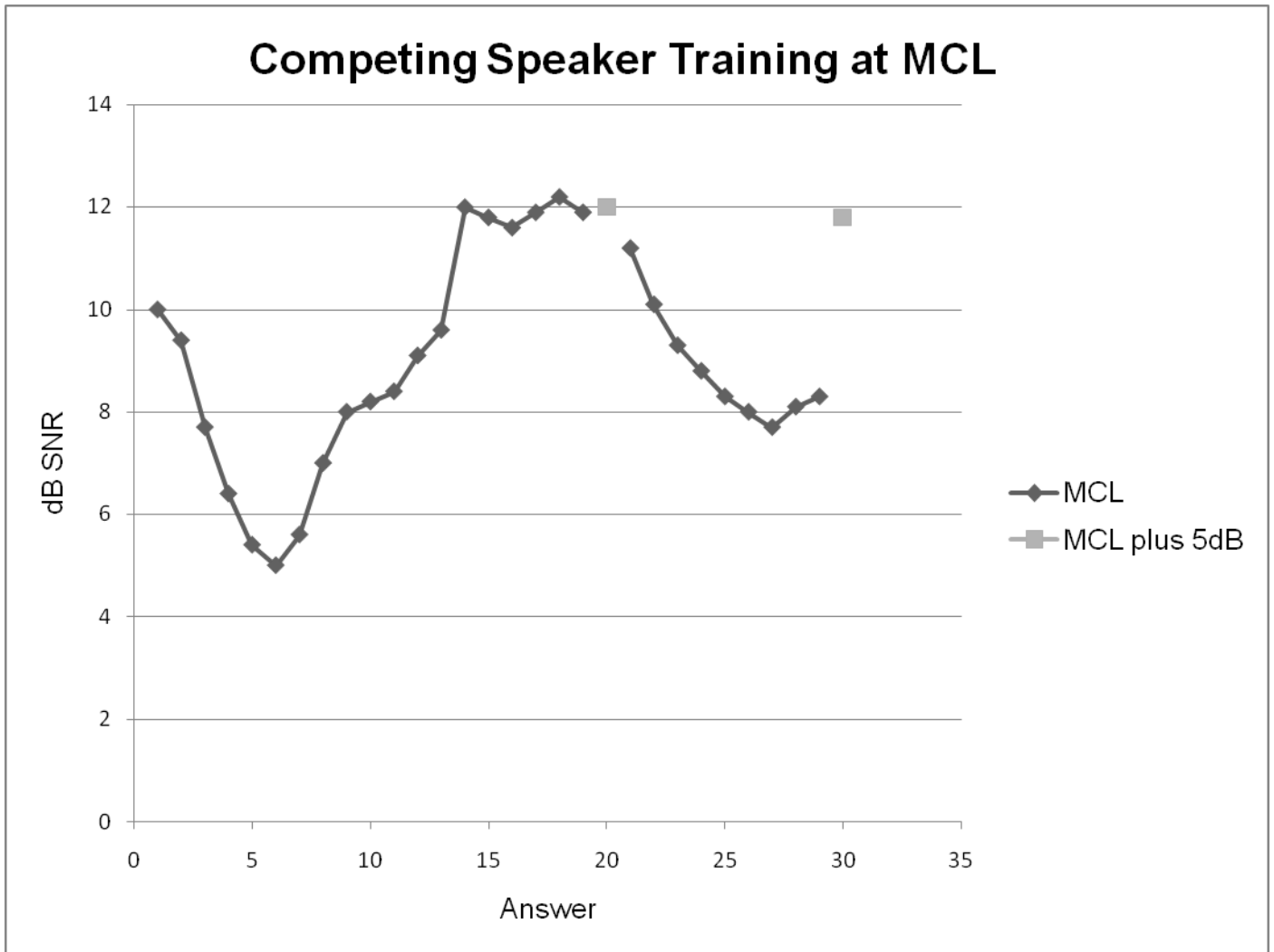


Image 2: Data as gathered from the competing speaker training exercises in LACE™. A decrease indicates an improvement in the ability to differentiate between and understand the content of incoming speech signals.

Appendix B  
LACE™ Training Data

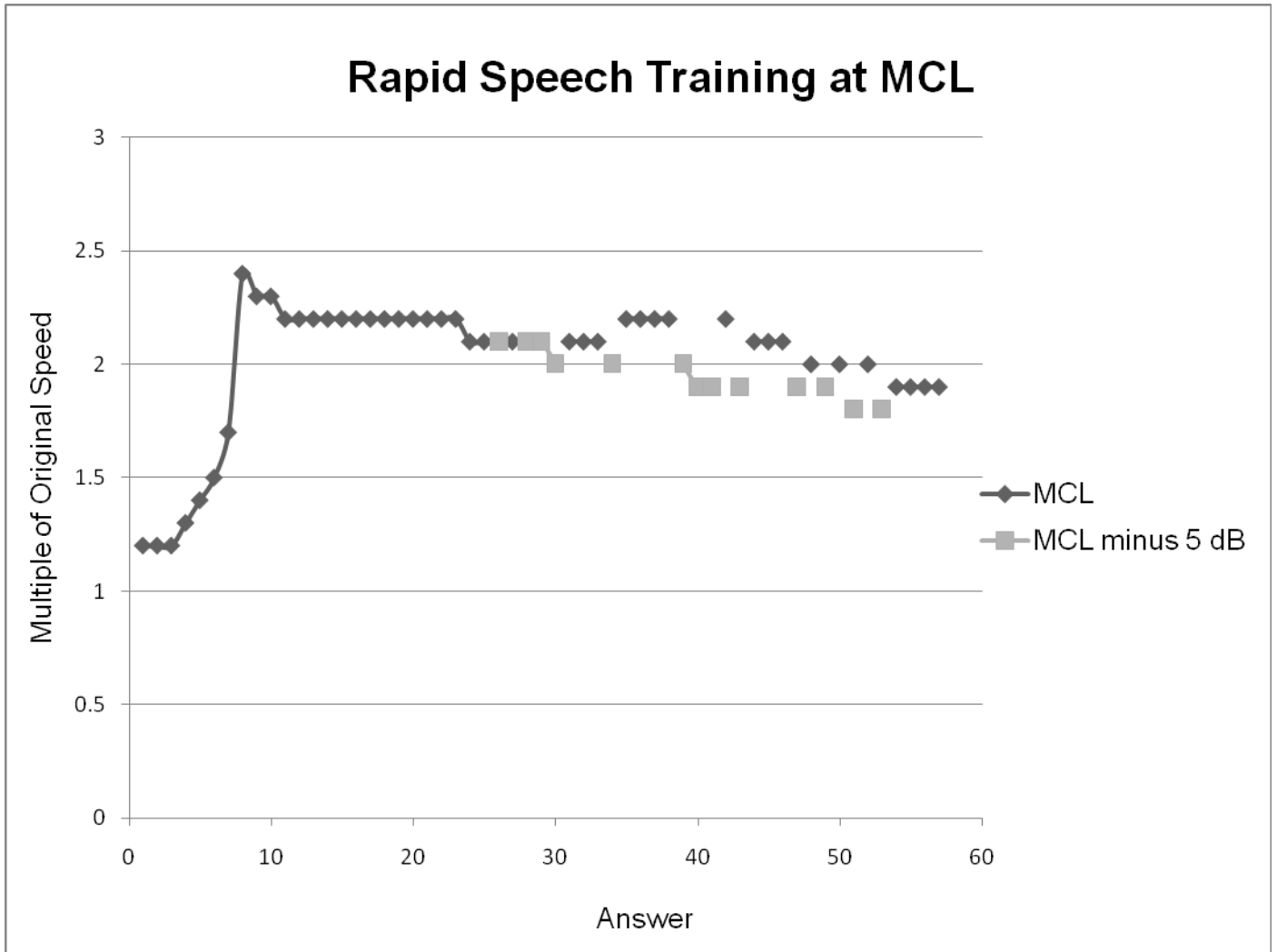


Image 3: Data as gathered from the rapid speech training tasks in LACE™. An increase indicates an improvement in the ability to understand speech that is presented with greater speed.

Appendix B  
LACE™ Training Data

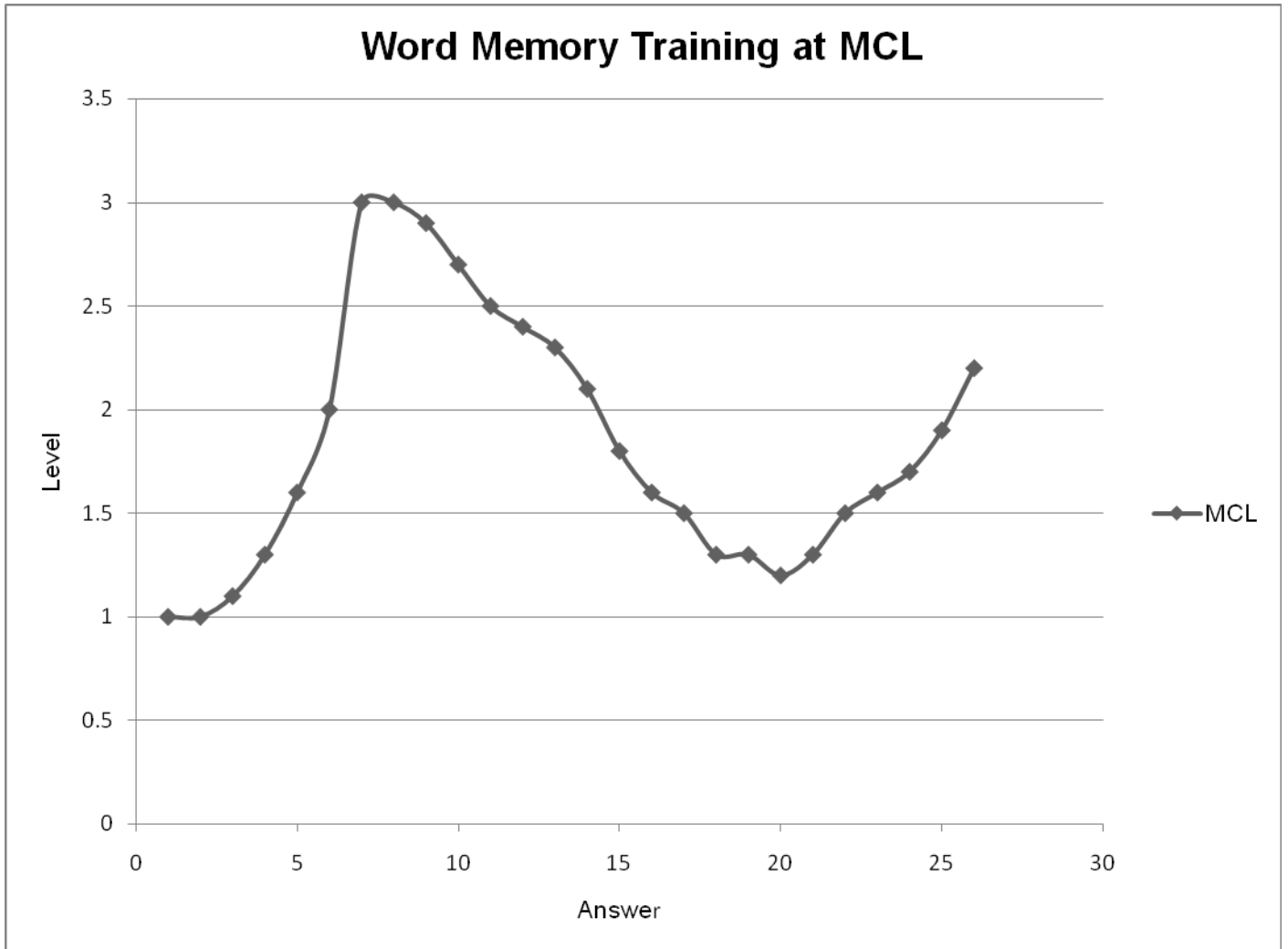


Image 4: Data as gathered from the word memory training exercises in LACE™. An increase indicates an improvement in the ability to remember a ‘target word’ and recognize the information surrounding this target.

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